DESIGN AND FABRICATION OF $BaTiO_3$ HUMIDITY SENSOR USING THICK FILM SCREEN PRINTING TECHNIQUE

WAN SUHAIMIZAN BIN WAN ZAKI

MASTER OF SCIENCE
UNIVERSITI PUTRA MALAYSIA

2006

DESIGN AND FABRICATION OF $BaTiO_3$ HUMIDITY SENSOR USING THICK FILM SCREEN PRINTING TECHNIQUE

By

WAN SUHAIMIZAN BIN WAN ZAKI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

June 2006

DEDICATION

This thesis is dedicated to my parents and the one i love for their constant support, love and guidance during all moments of my life.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

DESIGN AND FABRICATION OF $BaTiO_3$ HUMIDITY SENSOR USING THICK FILM SCREEN PRINTING TECHNIQUE

By

WAN SUHAIMIZAN BIN WAN ZAKI

June 2006

Chairman: **Rahman Wagiran, M.Sc.**

Faculty: **Engineering**

Thick film sensor technology has been recognized as an important technology in sensor manufacturing for the last decade. The technology contributes to the sensor development with the exploitation of the film itself as a primary sensing device. Most ceramic materials have been investigated as a humidity sensor mainly on porous structure prepared by thick film technology. These films have microstructure properties similar to those of sintered porous bodies, but the dimensions of the sensing devices can be reduced, which then can be used in hybrid circuits.

In this work, two types of analyses will be made based on Barium Titanate ($BaTiO_3$) dielectric material. The First one is to analysis the electrical properties of $BaTiO_3$ material in bulk and thick film forms and second analysis is to characterize thick film $BaTiO_3$ for a humidity sensor at room temperature. The $BaTiO_3$ powder was prepared through solid state reaction using a raw material Barium Carbonate ($BaCO_3$) and Titanium Dioxide (TiO_2). The thick film paste was prepared by mixing an organic vehicle with the sintered powder in appropriate ratio. The paste was then screen printed

onto a ceramic substrate in an interdigitated electrode pattern using DEK J1202 screen printing machine. The dielectric property of $BaTiO_3$ was investigated by varying the frequency in the range of 10Hz to 10 MHz using the Impedance Analyzer. The characterization of the thick film sensor with response to the Relative Humidity (%RH) was carried out in the Humidity Climatic Chamber in the range of 20%RH to 95%RH. LCR meter and PIC conditioning unit was used to measure the response of the $BaTiO_3$ thick film sample with the changes of the Relative Humidity..

The results showed that the dielectric response of the $BaTiO_3$ material in bulk and film samples are the same, based on the quasi dc concept. A smaller gap of interdigitated electrode pattern gave a higher response in dielectric properties compared to the bigger gap. The $BaTiO_3$ thick film sensor showed decrement in resistance and increment in capacitance with respect to the increases of Relative Humidity (RH). The voltage-humidity characteristic of the sensor showed a good linearity and the sensor response time is faster than the recovery time. The PIC conditioning circuit is designed to convert the analogue voltage into digital value and display the measurement result through Liquid Crystal Display (LCD) to make the system more user-friendly. As a conclusion, $BaTiO_3$ thick film shows a good promising material to be used as a humidity sensor based on thick film screen printing technology.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

MEREKABENTUK DAN FABRIKASI $BaTiO_3$ PENGESAN KELEMBAPAN MENGGUNAKAN TEKNIK CETAKAN FILEM TEBAL

Oleh

WAN SUHAIMIZAN BIN WAN ZAKI

Jun 2006

Pengerusi: Rahman Wagiran, M.S.

Fakulti: Kejuruteraan

Teknologi pengesan filem tebal telah dikenalpasti sebagai satu teknologi yang penting dalam fabrikasi pengesan untuk beberapa dekad yang lalu. Teknologi tesebut telah menyumbang kepada pembangunan pengesan dengan mengeksploitasikan filem tersebut sebagai pengesan primer. Kebanyakkan bahan seramik yang telah dikaji sebagai pengesan kelembapan tertumpu kepada pembentukkan struktuk bahan yang poros. Filem tebal mempunyai cirian mikro-struktur yang sama dengan struktur poros badan bahan kepingan yang di bakar, tetapi dimensi ukuran pengesan filem dapat dikecilkan untuk kegunaan dalam litar hibrid.

Dalam kajian ini, terdapat dua bentuk analisis dilakukan terhadap bahan dielektrik Barium Titanate ($BaTiO_3$). Analisis pertama adalah penciriian dielektrik bahan $BaTiO_3$ dalam bentuk kepingan tebal dan filem tebal dan analisis kedua adalah analisis cirian filem tebal $BaTiO_3$ sebagai pengesan kelembapan pada suhu bilik. Bahan $BaTiO_3$ disediakan melalui tindak balas keadaan solid yang terdiri dari campuran bahan asas Barium Karbonat ($BaCO_3$) dan Titanium Dioksida (TiO_2). Dakwat filem tebal $BaTiO_3$

pula dihasilkan melalui campuran bahan organik pembawa dan bahan $BaTiO_3$ melalui nisbah yang tertentu. Dakwat ini diskrin cetakan keatas alas seramik yang mempunyai konfigurasi jejari elektrod menggunakan mesin skrin cetakan filem tebal DEK J1202. Cirian dielektrik bagi bahan $BaTiO_3$ diukur dengan mengenakan frekuensi diantara julat 10Hz hingga 10MHz menggunakan *Impedance Analyzer*. Cirian filem tebal $BaTiO_3$ sebagai pengesan kelembapan dijalankan didalam bekas kelembapan *Climatic* dalam julat kelembapan Relatif (RH) antare 20%RH hingga 95%RH. LCR meter dan PIC litar keadaan digunakan untuk mengukur tindakabalas filem tebal bahan $BaTiO_3$ terhadap perubahan kelembapan relatif tersebut.

Keputusan kajian menunjukkan bahawa mekanisme cirian dielektrik bahan $BaTiO_3$ dalam bentuk kepingan tebal dan filem tebal adalah sama. iaitu berdasarkan konsep semi-dc (*quasi-dc*). Jarak pemisah antara dua elektrod yang dekat menunjukkan perubahan cirian dielektrik yang lebih tinggi dibandingkan dengan jarak jejari elektrod yang lebih besar. Filem tebal pengesan kelembapan $BaTiO_3$ menunjukkan penurunan nilai rintangan dan peningkatan nilai kapasitan dengan peningkatan nilai kelembapan relatif (RH). Cirian graf voltan-kelembapan menunjukkan lenkungan linear yang baik dan pengesan kelembapan memberikan masa tindak balas yang lebih pantas dibandingkan dengan tindak balas pembalikkan pengesan. Penggunaan Mikro-pengawal PIC sebagai isyarat keadaan membolehkan isyarat voltan analog ditukar kepada nilai digital dan hasil keputusan pengukuran kelembapan dipaparkan melalui paparan cecair kristal (*liquid crystal display*) menjadikan sistem ini lebih mesra pengguna. Kesimpulannya. filem tebal $BaTiO_3$ menunjukkan potensi yang baik untuk dijadikan bahan dalam pembuatan pengesan kelembapan menggunakan teknologi filem tebal.

ACKNOWLEDGEMENTS

In the Name of ALLAH, Most Gracious, Most Merciful

I would like to express my deepest gratitude to my supervisor, Mr. Rahman Wagiran for his endless support, guidance, wise words, encouragement, ideas and help throughout my research. I also want to thank my committee members, Prof. Abdul Halim Shaari and Dr. Samsul Bahari Mohd Noor for their support, information and ideas that committed in the success of this research work.

I would like to thank my parents and family and to all my friends especially to Mr. Walter and Faizal for their kind support, understanding and encouragement during the completion of my research.

Many thanks also goes to all my colleagues and UPM support staff.

I certify that an Examination Committee has met on 30th June 2006 to conduct the final examination of Wan Suhaimizan Wan Zaki on his Master of Science thesis entitled "Design and Fabrication of $BaTiO_3$ Humidity Sensor using Thick Film Screen Printing Technique " in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Senan Mahmod Abdullah, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Syed Javaid Iqbal, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Roslina Mohd Sidek, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Mansuri Othman, PhD
Professor
Faculty of Engineering
Universiti Kebangsaan Malaysia
(External Examiner)

HASANAH MOHD GHAZALI, PhD
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 28 AUG 2006

DECLARATION

I hereby declare that the thesis is based on my original work except for equations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

WAN SUHAIMIZAN WAN ZAKI

Date: 18/8/2006

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Å	Angstrom
AC	Alternating Current
Al_2O_3	Aluminum Dioxide
$BaCO_3$	Barium Carbonat
$BaTiO_3$	Barium Titanate
BCD	Binary Code Decimal
A/D	Analogue to Digital
C	Celsius
CMOS	Complementary Metal-Oxide Semiconductor
CVD	Chemical Vapor Deposition
DC	Direct Current
DIL	Dual in Line
DA	Data Acquisition
ESL	Electro-Sciences Laboratories
FET	Field Effect Transistor
g	gram
Hz	Hertz
IC	Integrated Circuit
IDE	Interdigitated Electrode
I/O	Input/output
kHz	kilo Hertz
LCD	Liquid Crystal Display

m	meter
MHz	Mega-Hertz
min	minute
ml	mililiter
mm	millimeter
mV	miliVolt
OH	Hydroxide
pF	pico Farad
R_{ref}	Reference Resistance
R_{sen}	Sensor Resistance
RAM	Random Access Memory
RH	Relative Humidity
RISC	Reduce Instruction Set Computer
ROM	Read Only Memory
rpm	round per-minute
SMU	Source Measurement Unit
sec	second
SEM	Scanning Electron Microscope
SPWM	Sinusoidal Pulse Width Modulation
SSFCL	Solid State Fault Current Limiter
SSTS	Solid State Transfer Switch
SVC	Static VAR Compensator
TiO_2	Titanium Dioxide
V	Volume

V_{out}	Voltage Output
V_{p-p}	Volt Peak to Peak
V_{ref}	Voltage Reference
wt	weight
XRD	X-Ray Diffraction
μm	micrometer

CHAPTER 1

INTRODUCTION

1.1 Introduction

In recent years, the demand for various kinds of physical and chemical sensors is increasing day by day [1]. Among these sensors, the measurement of humidity has received great attention due to the recognized importance of water partial pressure in many industrial processes and in the market of air-conditioning systems for the automatic regulation of living environments. With the advance and broadening applications of microprocessors, there are increasing efforts to develop humidity sensors based on variation electrical parameters for automated control system purpose. The trends towards automatic control systems has recently gained importance due to the increasing need in quality control of production process and products in various industries such as the production of electronic devices, precisions instruments, textiles and foodstuffs [2].

Many different materials have been studied for used as a sensor element in humidity measurement devices. Among them, ceramic oxides have shown advantages in terms of thermal, physical and chemical stability and mechanical strength [3]. The major factors that influence the humidity sensitivities of ceramic materials rely on its surface and microstructure. Thus, controlling porosity and surface area are important aspects in determining the humidity-sensitive electrical properties of ceramic products.

Most ceramic materials have been investigated as a humidity sensor mainly on porous structure prepared by film technology. These films have microstructure properties similar to the sintered porous bodies and the film structure is small and suitable for hybrid circuit application [4]. The basic components of measurement system in hybrid circuit may contain at least a sensor for measuring input, a processor for processing the data and an actuator to provide display or execute action as shown in Figure 1.1.

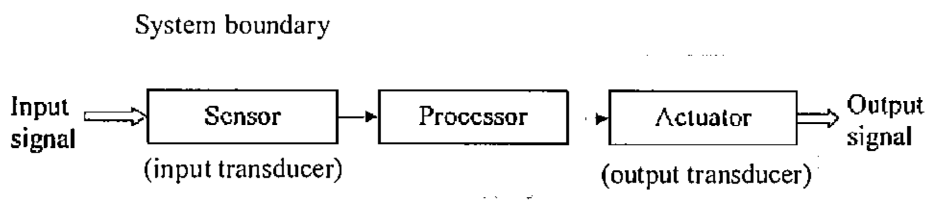

Figure 1.1: Basic Component of a Measurement System.

Great effort has been done to develop a hybrid circuit by merging all of the electronics components into single sensing module for miniaturization of electronic system which lead to a low cost, small and high reliability product. Integrating the sensing element with microprocessor unit, will make the sensor become a smart system. The smart sensor system is defined as a system having a powerful and localized processing capability, allows many of the data handling aspect of measurement to be devolved down to the sensor itself, leaving the host computer free to manage the procedural aspect of the whole system [5]. A system that is able to convert analogue signal to digital signal, where the functions such as linearization, temperature compensation, and signal processing can be included in the package to provide higher level information processing is also termed as a smart sensor [6].

1.2 Problem Statement

Silicon planar technology is widely used in the fabrication on today's sensor mainly on integrated smart sensor. This technology posses many valuable characteristics for sensor applications and it's provides a high degree of integration into microelectronic sensor subsystem by using standard processing techniques. Currently, the major drawback of silicon sensors concerns their ability to provide a cost-effective solution to a particular problem such as to fulfill demand on low-to-medium-volume of requirement sensors per year [7].

An alternative approch in producing an integrated sensor with a low cost and reliable small electronic system is through thick film hybrid circuit. This hybrid circuit is generally regarded as being compact, robust and relatively inexpensive and have found application in areas such as televisions, calculators, telephones, automotive electronics and many more [7]. The flexibility offer in thick film process either in preparation of thick film materials or by the choice of shape and size of the thick film sensor structure give advantage over silicon technologies. In fabrication of thick film sensors, a lot of